T&B Systems
environmental research associates

Technical & Business Systems
859 Second Street, Santa Rosa CA 95404
(707) 526-2775 Fax (707) 579-5954
E-mail: donl@tbsys.com

SUBTASK MEMORANDUM

Task: 1.3 Adequacy and validity of meteorological measurements

Subtask: 7 - Assess the usefulness of the routine airplane temperature soundings

From: Don Lehrman

Date: 2/1/04

The objective of this task was to assess the usefulness of the routine airplane temperature soundings for determining atmospheric stability and mixing heights. Given the rather unsophisticated method of measurement and quality assurance, and the height interval of the readings (500 ft) there is a question if the data were of a high enough quality and vertical resolution for use in regional air quality studies and model input. Aircraft soundings are made at 5 PST when the atmosphere is in its most stable state thus some interpolation of conditions during afternoons when the atmosphere has destabilized is required. Moreover, there is some concern that meteorological conditions conducive to high particulate loading would also frequently reduce ceilings and visibility to below minimums required for aircraft operations.

A 15-month set of measurements, which coincidently are sponsored by ARB, were obtained for Central California. On days when rawinsonde observations were conducted at Fresno and Bakersfield as part of the CRPAQS winter program, observed maximum mixing heights were compared to mixing heights computed from the aircraft temperature soundings and maximum daily surface temperature at Fresno and Bakersfield.

For the airplane soundings, maximum mixing height was computed using a variation of a method described by Holzworth (1972). The aircraft temperatures were converted to potential temperature Θ using the following equation:

$\Theta = T^*(\text{Pressure}/1000\text{ mb})^{\kappa}$,

where $\kappa \sim 2/7$, T is temperature in deg Kelvin, and P is pressure in millibars.

A pressure was assigned to the standard 500 feet levels at which airplane readings are made using the standard atmosphere. This enabled a potential temperature profile to be readily calculated for each airplane sounding. It was further assumed that the maximum daily surface temperature in degrees Kelvin was not significantly different from the potential temperature at the surface (a pretty solid assumption). The mixing height was determined objectively by computing at what elevation the surface potential temperature intersects the sounding profile.

Rawinsonde mixing heights were determined by two methods. The first method can best be shown by example. Figure 1 shows the vertical profiles of temperature, relative humidity, winds and ozone from an ozonesonde/rawinsonde sounding. Vigorous mixing to approximately 600 m is implied from the nearly constant ozone and humidity. The temperature profile shows a minor stable layer at the altitude followed by a substantial inversion that effectively decouples the boundary layer. Limited mixing is suggested between 600 m and the base of the inversion at 750 m. As in this example, wind shear is often evident at the top of the boundary layer as well. At the base of the temperature inversion at 750 m, ozone and humidity decrease significantly and winds shift from the west-northwest to southwest. During CRPAQS, ozone was not measured but the other parameters were. The second method was developed at T&B Systems whereby the top of the surface turbulence layer is estimated using the variation in balloon ascension rate. An example of a vertical velocity profile and temperature profile are shown on Figure 2.

Results were mixed but generally mixing heights agreed quite well considering the completely different methods employed; most notably at Fresno. The estimated mixing heights are shown in Table 1, and summarized on Figure 3. In the table all CRPAQS winter IOPs are included

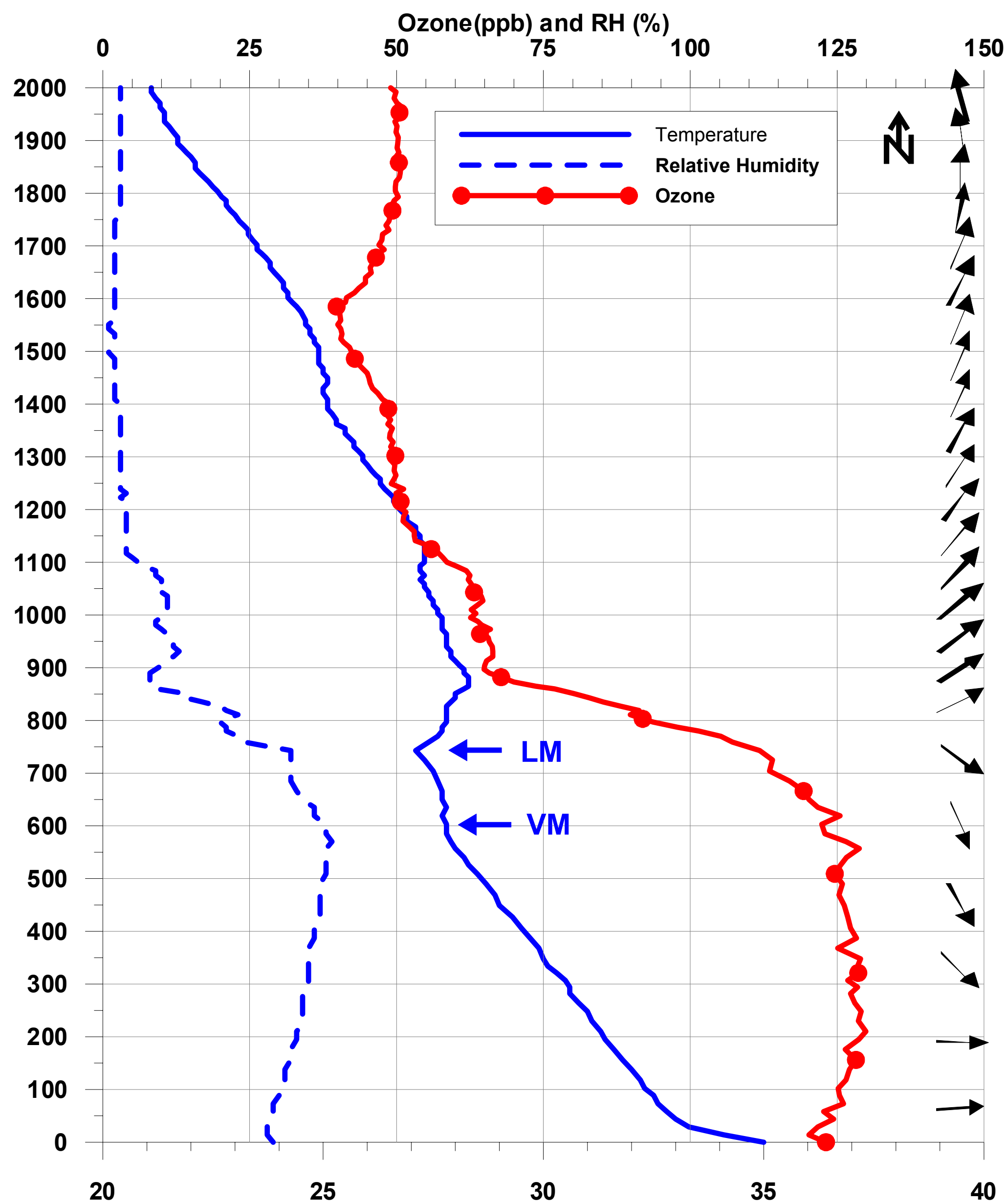


Figure 1. Example of Mixing Height Estimate Using Rawinsonde Sounding.

Showing Temperature (bottom axis), Relative Humidity (top axis) Ozone (top axis), and Winds (vector with north up).VM indicates top of vigorous mixing. LM indicates top of limited mixing.

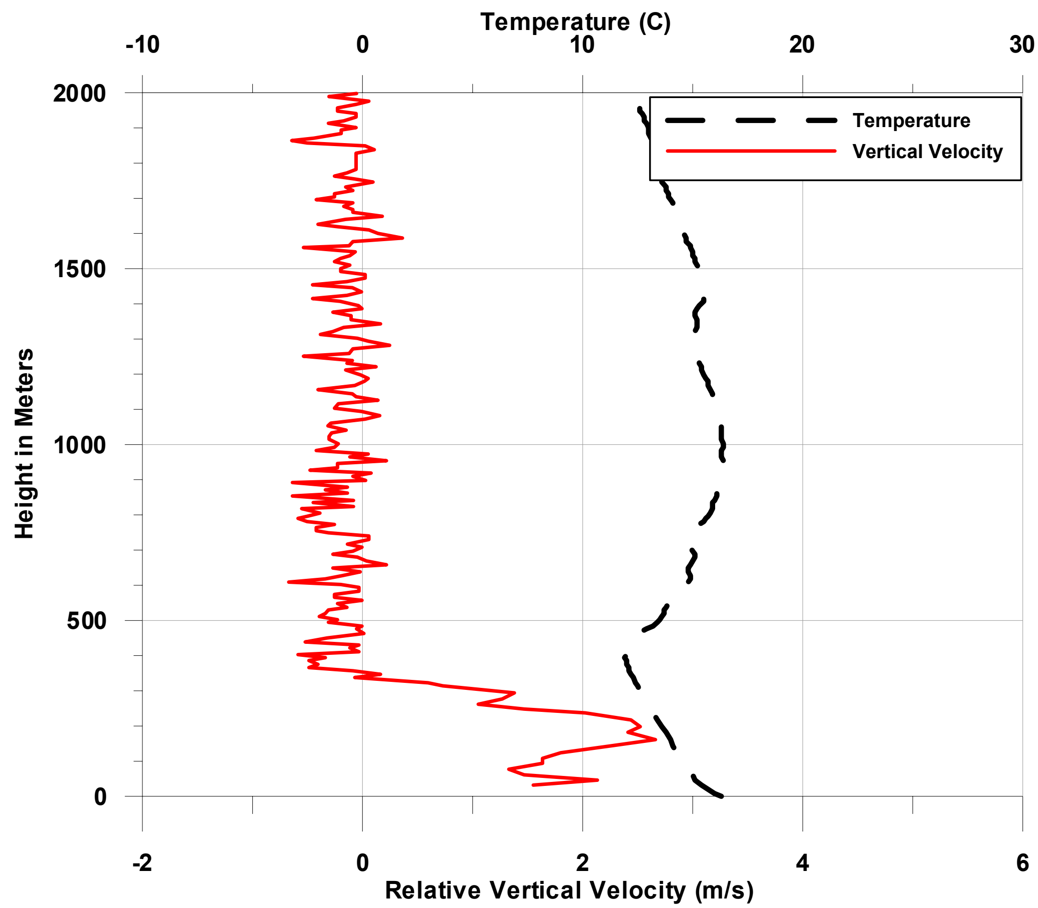
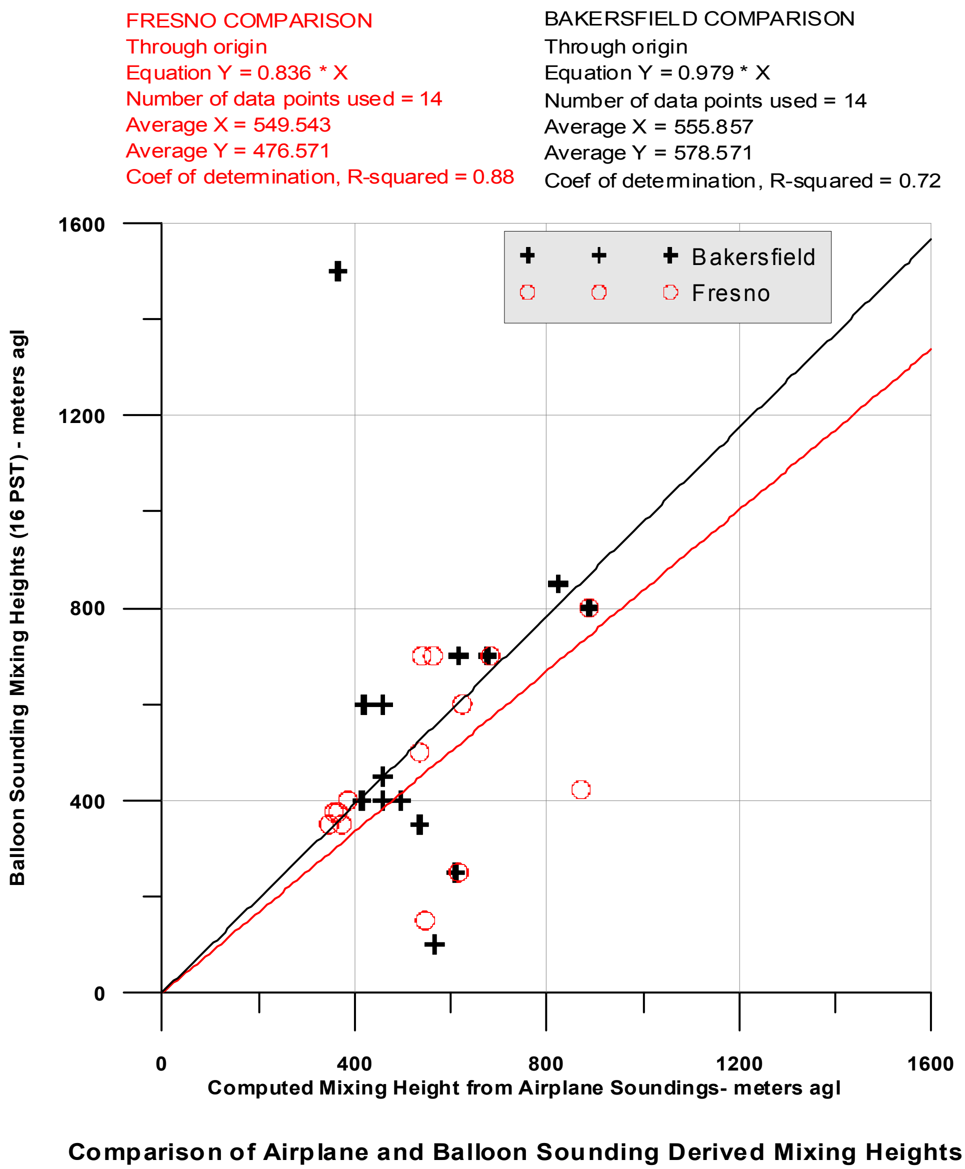


Figure 2. Showing Estimated Vertical Velocity and Temperature Profile from Fresno Rawinsonde Taken at 16 PST on January 4, 2000.



2/27/04

Figure 3. Comparison of Airplane and Rawinsonde Derived Mixing Heights

when there was both airplane and rawinsonde data. It is noteworthy that even though the CRPAQS episodes occurred when fog and particulate loading produced generally low visibilities and meteorological conditions caused low ceilings, only two airplane soundings were missed. It can be seen that the Fresno data compared quite well with the exception of three days. Further examination of the meteorology on those outlier days revealed that strong low-level warming occurred during the diurnal cycle and that the temperature profile at 5 PST was not representative of conditions in the afternoon when maximum mixing occurs.   This factor is noted in the table comments. Similarly, two of the outliers at Bakersfield were due to extreme atmospheric warming during the day, but others could not be attributed to this, most notably on December 15. Excluding the three days in Fresno and two days in Bakersfield when conditions were changing rapidly, the average difference in mixing height estimates was 124 meters at Fresno and 214 meters at Bakersfield.   A major contributor to the high discrepancy at Bakersfield was December 15.

The data are plotted on Figure 3 along with best-fit linear regressions. Although the slopes of the regression lines are both near unity, the variance as expressed by R-squared is very good for Fresno (0.98) but poor for Bakersfield (0.71). At both locations, the rawinsonde sites were comparable distances from the airports and the terrain was relatively uniform so the disparity in the Bakersfield estimates is not understood.

In summary, the aircraft data can provide useful, often accurate mixing height information if the general meteorological conditions are not rapidly changing during the day. With that caveat, it is recommended that the other ARB airplane soundings in Central California be utilized in this manner wherever RWP or RASS data are not available. Other airplane sounding locations of relevance to CRPAQS are at airports in Sacramento, Modesto, and Trimmer.

Table 1. Summary of Mixing Height Determined from Aircraft and Rawinsondes

Station	Date	Mixing Height meters-agl		difference meters	Comments
		Aircraft	Rawinsonde		
Bakersfield	15-Dec	365	1500	1135	from vertical velocity charts
Bakersfield	16-Dec	457	450	7	
Bakersfield	17-Dec	615	700	85	
Bakersfield	18-Dec	567	100	467	Atmosphere warmed 4 oC
Bakersfield	26-Dec	535	350	185	
Bakersfield	27-Dec	458	400	58	
Bakersfield	28-Dec	459	600	141	Atmosphere warmed 4 oC
Bakersfield	4-Jan	495	400	95	
Bakersfield	5-Jan	415	400	15	
Bakersfield	6-Jan	567			no rawinsonde sounding
Bakersfield	7-Jan	610	250	360	
Bakersfield	31-Jan				no airplane sounding
Bakersfield	1-Feb	418	600	182	
Bakersfield	2-Feb	823	850	27	
Bakersfield	3-Feb	677	700	23	from vertical velocity charts
Fresno	15-Dec	888	800	88	
Fresno	16-Dec	871	422	449	Atmosphere warmed 6 oC during day
Fresno	17-Dec	347	350	3	from vertical velocity charts. 2 layers. Top = 750m
Fresno	18-Dec	616	250	366	Atmosphere warmed 8 oC
Fresno	26-Dec				no airplane sounding
Fresno	27-Dec	373	350	23	
Fresno	28-Dec	535	500	35	
Fresno	4-Jan	357	375	18	
Fresno	5-Jan	365	375	10	
Fresno	6-Jan	387	400	13	
Fresno	7-Jan	547	150	397	Atmosphere warmed 4 oC
Fresno	31-Jan	682	700	18	
Fresno	1-Feb	624	600	24	
Fresno	2-Feb	563	700	137	
Fresno	3-Feb	540	700	160	

	Average Difference(m)
Fresno	124
Bakersfield	214